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ZARAGOZA AB
FOG STUDY

by

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13 Abstract: This report documents efforts to provide an objective technique for forecasting the onset of fog and visibilities below certain specified thresholds at Zaragoza AB, Spain. The study was in response to a problem with dense fog at Zaragoza. The report addresses the problem in two parts; first, with tables that identify the number of hourly observations of fog at Zaragoza, stratified by certain weather variables, and second, with a fog forecasting model based on discriminant analysis that provides an estimated probability of a specified visibility threshold as a function of time.

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PREFACE

This report documents the results of USAFETAC Project 81028. In its support assistance request, Detachment 16, 31st Weather Squadron, Zaragoza AB, Spain, asked for "an objective technique for forecasting the onset and degree of visibility below certain specified thresholds." Zaragoza AB (41° 40' N, 1° 3' W, elevation 263 meters, Block Station Number 081605) is prone to lengthy episodes of dense fog from November through February. Zaragoza is surrounded by mountain ranges in all quadrants; the only opening is to the east-southeast, toward Barcelona. Visibility problems occur after Atlantic Lows and associated troughs pass through the area and a shallow cold air mass establishes itself in the valley. Until something warms the air or forces it out of the area, the fog becomes progressively worse.

USAFETAC/DNY satisfied this request in two parts. The first part provided for creation of conditional climatology tables that identify the number of hourly observations of fog at Zaragoza, stratified by certain weather variables. The second part was a fog forecasting model based on discriminant analysis that provides an estimated probability of a specified visibility threshold as a function of time.

Primary project analysts were Mr Charles R. Coffin and Capt Anthony J. Warren, USAFETAC/DNY.

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1. INTRODUCTION

1.1 Purpose. Although dense fog has a significant effect on airfield operations everywhere, some locations are more prone to the condition than others. At Zaragoza AB, Spain, for example, long periods of dense fog are common between November and February, and accurate forecasts of fog onset and duration is especially important here. To help Zaragoza weather forecasters deal with the fog problem better, USAFETAC/DNY prepared a set of conditional climatology tables for fog forecasting and developed a model intended to estimate the probability of fog during the next 3, 6, 12, and 24 hours.

1.2 Components of the Study. This study is in two parts, both of which use operationally significant visibility thresholds of 800, 1,600, 3,200, and 5,000 meters. The first part, described in Section 2, is a set of descriptive statistics (conditional climatology tables) that relate the observed frequency of fog to various surface-based weather variables such as wind speed and dew-point depression. The second part describes (in Section 3) a fog forecasting model based on discriminant analysis that provides an estimated probability of a specified visibility threshold as a function of time.

1.3 Data Sources. The data used in this study included Zaragoza AB surface observations and upper-air data from Barajas, Spain (40° 27' N, 3° 33' W, elevation 582 meters, Block Station Number 082210). The period of record for both datasets was January 1973 through September 1990. Barajas, 134 NM northwest of Zaragoza, is the closest upper-air station that provides consistent data (every 12 hours). The availability of surface observations from Barajas, however, is very irregular and limits its usefulness in a forecasting model. In any case, we found little correlation between Barajas and Zaragoza fog observations from the observational data that was available.

2. CONDITIONAL (FOG) CLIMATOLOGY AT ZARAGOZA AB

2.1 Frequency. Fog occurs frequently at Zaragoza between November and February. To illustrate, Table 1 shows the monthly frequency of occurrence of fog for each of the four specified visibility thresholds. Because Zaragoza fog is rare from March through October, we limited further analysis to November through February.

TABLE 1. Number of days with fog (stratified by visibility) by month (January 1973 - September 1990).

MONTH	VISIBILITY (meters) < 800	< 1,600	< 3,200	< 5,000
January	108	132	171	190
February	31	48	100	126
March	5	12	42	87
April	2	6	17	50
May	2	5	12	51
June	2	3	8	32
July	1	1	5	12
August	0	0	2	24
September	2	6	23	51
October	15	25	57	101
November	64	96	131	178
December	126	147	173	212

2.2 Duration. Table 2 gives the median duration of fog events at Zaragoza; it shows clearly the size of the Zaragoza problem. Fog often persists for several hours, even in the lower visibility ranges.

TABLE 2. Duration of fog events (hours) stratified by visibility category and month (50th and 95th percentile).

	VISIBILITY (meters)							
	< 800		< 1,600		< 3,200		< 5,000	
MONTH	50	95	50	95	50	95	50	95
January	6	23	7	23	7	26	9	28
February	3	18	3	19	3	14	4	17
March	3	4	1	10	2	7	3	8
April	0	0	2	2	3	5	3	6
May	1	2	1	4	3	5	2	5
June	4	7	2	8	2	9	2	6
July	0	0	0	0	1	1	2	4
August	0	0	0	0	1	1	2	4
September	4	7	2	7	2	5	3	6
October	2	9	2	11	2	13	4	10
November	4	22	4	20	6	22	6	24
December	8	24	9	25	8	26	11	28

2.3 Relationships to Other Variables. Frequency of fog occurrence by visibility threshold as a function of various other weather variables is shown in Tables 3 through 6. Table 3 is stratified by wind direction, Table 4 by wind speed, Table 5 by dew-point depression, and Table 6 by time of day. All these tables show that fog occurs most often (1) between 0800 and 1000Z, (2) when winds are calm or light southeasterly, and (3) when the dew-point depression is small.

TABLE 3. Percent Occurrence Frequency of fog (stratified by visibility category) as a function of wind direction.

	FOG (Visibility Category in Meters)					
WIND DIRECTION	≤800	801-1,600	1,601-3,200	3,200-5,000	≥5,000	NO FOG
CALM	6.8	1.9	3.3	4.2	6.7	77.2
1-30	0.4	0.1	1.2	1.4	2.9	94.0
31-60	0.8	0.9	1.7	2.7	4.2	89.7
61-90	2.0	1.4	2.6	3.4	4.8	85.8
91-120	3.8	1.4	2.3	4.0	5.5	83.1
121-150	6.4	1.4	1.9	3.4	5.3	81.6
151-180	5.1	1.5	1.8	2.7	6.3	82.7
181-210	2.1	0.3	1.0	1.4	4.3	91.1
211-240	0.4	0.2	0.4	0.9	4.1	94.0
241-270	0.8	0.1	0.4	0.8	1.6	96.3
271-300	0.5	0.2	0.3	0.7	1.7	96.7
301-330	0.3	0.1	0.3	0.6	1.0	97.7
330-360	0.2	0.1	0.2	0.5	0.8	98.2

TABLE 4. Percent Occurrence Frequency of fog at Zaragoza AB (stratified by visibility category) as a function of wind speed.

	FOG (Visibility Category in Meters)					
WIND SPEED (knots)	≤ 800	801-1,600	1,601-3,200	3,200-5,000	≥5,000	NO FOG
CALM	6.7	1.8	3.2	4.2.	6.9	77.3
1-3	3.2	1.1	2.1	3.1	4.9	85.7
4-6	1.7	0.7	1.0	1.9	3.5	91.2
7-10	0.5	0.3	0.5	1.0	1.7	95.9
11-16	0.1	0.0	0.1	0.4	0.8	98.6
> 16	0.0	0.0	0.0	0.1	0.2	99.7

TABLE 5. Percent Occurrence Frequency of fog (stratified by visibility category) as a function of dew-point depression.

DEW-POINT DEPRESSION	FOG (Visibility Category in Meters) ≤ 800	801-1,600	1,601-3,200	3,200-5,000	≥ 5,000	NO FOG
0	42.6	6.6	7.2	5.5	6.4	31.8
0.1-2.0	12.5	5.0	7.1	7.7	10.5	57.1
2.1-4.0	2.7	2.0	3.9	6.4	10.5	74.5
4.1-6.0	1.3	0.7	2.0	3.9	7.4	84.7
6.1-10.0	0.0	0.1	0.7	1.8	3.4	93.9
> 10.0	0.0	0.0	0.0	0.2	0.6	99.1

TABLE 6. Percent Occurrence Frequency of fog (stratified by visibility category) as a function of time.

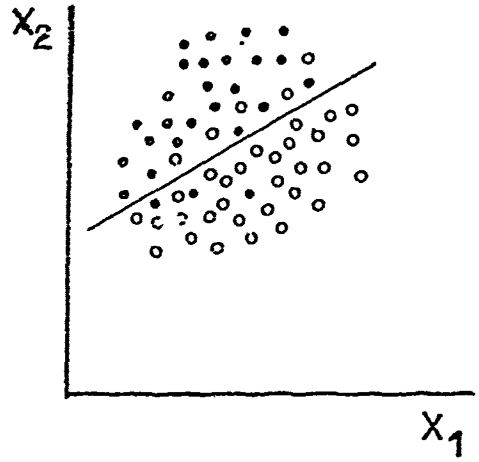
HOUR(Z)	FOG (Visibility Category in Meters) ≤ 800	801-1,600	1,601-3,200	3,200-5,000	≥ 5,000	NO FOG
23-01	1.8	0.3	0.5	0.8	2.5	94.2
02-04	2.1	0.4	0.6	1.1	3.2	92.5
05-07	2.8	0.7	1.4	2.9	5.9	86.3
08-10	3.0	1.3	2.5	3.5	4.6	85.1
11-13	1.4	0.8	1.6	2.2	2.6	91.4
14-16	0.8	0.4	0.9	1.4	1.2	95.4
17-19	1.1	0.5	0.8	1.0	1.5	95.1
20-22	1.6	0.3	0.4	0.8	1.8	95.2

3. THE FORECAST MODEL

3.1 Discriminant Analysis

3.1.1 *Introduction.* Discriminant analysis is a statistical technique that classifies individual observations into groups. For a fog forecast model, the groups are either YES or NO for fog occurrence for four visibility thresholds and four time periods. Sixteen separate models were developed for this study.

3.1.2 *Basic Concept.* To illustrate the basic principles of discriminant analysis, consider a simple forecast model consisting of two predictors (X_1 and X_2). On a conventional Cartesian plot (shown to the right), a closed circle would be plotted for the observed value at each of the predictors when fog is not subsequently observed at the verification hour; an open circle would be plotted when fog *is* observed. After all the data is plotted, a line that best separates the two categories is drawn. This line, referred to as the "discriminant," serves as the basic forecast model. Subsequent observations of X_1 and X_2 would then be plotted to obtain a forecast. A forecast of "fog" or "no fog" is based upon which side of the discriminant the point lies.



3.1.3 *Multivariate Analysis.* In practice, there is no reason to limit the number of predictors to two, but using more would make the plot multi-dimensional and impossible to visualize conceptually. Using more than two predictors, however, poses no problem to a computer. To evaluate on which side of the discriminant a point lies, a mathematical function known as a "discriminant function" is used. This function returns a value between 0 and 1, the numbers relating to the distance the point lies from the discriminant. Values greater than 0.50 indicate a forecast of "fog," while values of less than 0.50 forecast "no fog." Points farther from the discriminant are associated with discriminant function values approaching either zero or one, indicating greater confidence in the subsequent forecast. Points closer to the discriminant are associated with discriminant function values of about 0.50 and have a large degree of uncertainty. To first order, the values returned from the discriminant function can be interpreted as an estimate of the probability of fog occurring; that is, a value of 0.65 represents about a 65% chance of fog.

3.1.4 *Model Predictors.* To select which variables to use as predictors in the discriminant analysis, a technique known as "stepwise selection" was used. Initially, over 50 proposed variables were considered by each model; these included the Barajas 850-mb wind direction and speed, 850-mb temperature and dew point depression, a flag indicating whether or not an inversion was present, the strength of the inversion, and the inversion height. Potential surface predictors included temperature, dew point, dew point depression, wind speed, sea-level pressure, and the hour. The stepwise selection process analyzed all potential predictors and identified the best. None of the upper air variables were selected. In fact, only seven predictors were selected for all 16 models, these predictors were: time (hour), dew-point depression, sea-level pressure, dry-bulb temperature, ceiling, and wind speed/direction. To avoid an abrupt jump between 23 and 00Z, the model computed the cosine and sine of the "hour angle" (defined as hour-23/360° + 360°) instead of the actual hour. Various forms of these predictors appear in the model equations Table 7 lists the variables selected for each model.

Table 7. **Predictors used in discriminant analysis models.** The following predictors were used by all models: temperature, dew-point depression, sea-level pressure, and current visibility. An "X" in the chart indicates that the variable was used in the corresponding model. Abbreviations used in the table are: THRESH - Visibility Threshold, HR - Time of forecast (e.g., "3" is a 3-hour forecast), WD - wind direction (degrees), WS - wind speed, COS(WD) - cosine of the wind direction, SIN(WD) - sine of the wind direction, COS(HH) - cosine of the hour angle, SIN(HH) - sine of the hour angle; CIG - ceiling.

THRESH	HR	WD	WS	COS(WD)	SIN(WD)	COS(HH)	SIN(HH)	CIG
800	3				X		X	X
	6				X		X	X
	12		X			X	X	
	24				X	X		X
1600	3	X			X		X	X
	6				X		X	X
	12		XX		X	X	X	X
	24		X		X	X		X
3200	3	X	X		X	X		X
	6		X		X		X	X
	12		X		X		X	X
	24	X	XX			X		X
5000	3	X	XX			X		X
	6		X		X		X	X
	12		XX		X		X	X
	24	X	X		X	X		X

3.1.5 *Discriminant Function.* The discriminant functions were computed only from 1973-1988 data. Data from 1989-1990 was then used to independently evaluate the skill in the model. The computations involved for each of these individual models are complex, but an example of calculating the probability of fog with visibility less than or equal to 3200 meters, 6 hours from now, follows:

First, compute the value of the two coefficients A_1, A_2 and, B_1, B_2:

$$A_1 = -7567 - 2.23*DD + 1.47*SLP + 17.98*\sin(WD) + 3.36*T$$

$$A_2 = (8.86 \times 10^{-4})*CIG + 1.71*\sin(HH) + 1.48*WS + (5.64 \times 10^{-3})*VSBY$$

$$B_1 = -7551 - 2.33*DD + 1.48*SLP + 18.64*\sin(WD) + 3.29*T$$

$$B_2 = (8.84 \times 10^{-4})*CIG + 1.32*\sin(HH) + 1.46*WS + (5.23 \times 10^{-3})*VSBY$$

where

DD = dew-point depression (°F)

SLP = sea-level pressure (millibars)

T = temperature (°F)

CIG = ceiling height (feet AGL--60,000 used for no ceiling)

HH = current hour angle

WS = wind speed (knots)

WD = wind direction

VSBY = visibility (meters)

Next, the coefficients A and B are determined using:

$$A = A_1 + A_2$$

$$B = B_1 + B_2$$

The probability of fog (P) is then determined from:

$$P = [\exp(A - B) + 1]^{-1}$$

Sixteen sets of equations are required. This type of model is only practical when used with a computer. The customer was provided with a computer program with which to compute fog probability.

3.1.6 ***Self-Consistency of the Model.*** Various methods were attempted in determining the terms of the numerical values in the above equations. The best skill scores were obtained when the discriminant calculation was performed on the entire population. As a result, each equation is **independent** of the others This could lead to inconsistent results, such as the probability of fog with a visibility less than 1,600 meters being 0.3, while the same probability for a visibility of less then 800 meters was 0.5. These results, of course, conflict. Since the models for higher visibilities have higher skill scores than those for lower visibilities, we adjusted the probabilities for the lower visibility categories so that they cannot exceed the probability for any higher category. In this example, our model would provide a value of 0.3 for both the 800-meter and the 1,600-meter threshold. In this sense, the model is self-consistent.

3.2 Model Evaluation

3.2.1 *Heidke Skill Score.* The Heidke skill score (HSS) is used as defined in AWS/TR-235, pp. 43-47. The HSS, which ranges from 0 to 1, measures the accuracy of a given forecast over climatological chance; an HSS of 1 indicates perfect skill, while zero indicates no skill. USAFETAC's experience is that the HSS threshold for identifying skillful forecast models is about 0.4, but this choice is arbitrary. A better way to evaluate an HSS is to compare it with one produced from an alternative technique, such as a model based on persistence. HSSs obtained with the discriminant analysis model are given in Table 8a.

Table 8a. Heidke skill scores of the discriminant analysis model.

	TIME PERIOD			
VISIBILITY THRESHOLD	3 hr	6 hr	12 hr	24 hr
800 meters	0.29	0.22	0.18	0.11
1,600 meters	0.39	0.32	0.26	0.20
3,200 meters	0.57	0.45	0.37	0.30
5,000 meters	0.69	0.61	0.44	0.36

3.2.2 *Persistence Model.* A simple model based solely on persistence was also developed and tested on the 1989-1990 dataset. Table 8b gives Heidke skill scores for the 16 categories. Note that they are fairly high, especially in the short term. This suggests that any model will have difficulty forecasting with greater skill than persistence alone.

Table 8b. Heidke skill scores of the persistence model.

	TIME PERIOD			
VISIBILITY THRESHOLD	3 hr	6 hr	12 hr	24 hr
800 meters	0.54	0.38	0.17	0.28
1,600 meters	0.62	0.45	0.25	0.30
3,200 meters	0.70	0.56	0.43	0.44
5,000 meters	0.77	0.66	0.56	0.53

3.3 Model Comparisons

3.3.1 *Heidke Skill Scores.* Comparison of the HSS statistics in Tables 8a and 8b clearly show that the discriminant analysis model, used by itself, does not perform better than persistence alone. For 3-hour forecasts, persistence is clearly the better model.

3.3.2 *Discussion.* Failure of the discriminant analysis model to outperform persistence is a reflection of the persistence model's very high skill scores. With this being the case, it is recommended that operational forecasts not be based solely on the results of the discriminant analysis model. This model provides forecasters an *estimate* of the probability of fog for each visibility threshold, however, and those probability estimates should be considered in the overall forecast decision process. With time, further consideration of subjective factors (such as the synoptic situation or weather at stations upstream) may result in improved forecasts. It will still be difficult, however, for any technique to beat the high skill scores obtained for a 3-hour forecast by persistence.

4. SUMMARY AND CONCLUSIONS

4.1 Summary. Fog can occur at Zaragoza AB any time of year, but it is most frequent from November through February. Episodes of dense fog can be lengthy, median duration of fog with visibility less than 800 meters is 8 hours, and episodes exceeding 24 hours are not unheard of. There is a correlation between fog occurrence and several meteorological variables. USAFETAC/DNY developed a model that uses multivariate discriminant analysis to estimate fog probability; probabilitites for 3 , 6-, 12-, and 24-hour intervals for four visibility thresholds: 800, 1,600, 3,200, and 5,000 meters were provided. The Heidke skill score was used to evaluate the model; it showed considerable skill but was unable to outperform forecasts based on persistence. As a general rule, the higher the visibility threshold and the shorter the time period, the better the model forecast.

4.2 Conclusions. The USAFETAC-developed model should not be the sole input into an operational fog forecast. The probabilities, however, should be incorporated into a forecaster's decision-making process. Addition of certain subjective factors, such as the current synoptic situation, may result in forecasts that improve on persistence.

GLOSSARY

AGL	above ground level
CIG	ceiling height (feet)
DD	dew-point depression (F)
HH	current hour angle
HR	current hour (Z)
HSS	Heidke skill score
SLP	sea-level pressure (mb)
T	temperature (F)
THRESH	visibility threshold (meters)
VSBY	visibility (meters)
WD	wind direction (degrees)
WS	wind speed (knots)

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NWS Training Center, 617 Hardesty, Kansas City, MO 64124 1
NCDC Library (D542X2), Federal Building, Asheville, NC 28801-2723 1
NIST Pubs Production, Rm A-405, Admin Bldg, Gaithersburg, MD 20899 1
DTIC-FDAC, Cameron Station, Alexandria, VA 22304-6145 2
AUL/LSE, Maxwell AFB, AL 36112-5564 1
AWSTL, Scott AFB, IL 62225-5438 35